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Nichole Cicchetti, Bazle Haque, Shridhar Yarlagadda

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UNIVERSITY OF DELAWARE
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220 HULLIHEN HALL
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14. ABSTRACT

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-Monolithic Al5083
-Baseline
-Proposed seam design of thickened edges
-Inefficient solution
-Ceramic tiles with and without gap with the adhesive layer modeled
-AutoDyn accurately models the behavior of the adhesive
-Proposed seam design of step ladder
-Reasonable possible solution
AutoDyn material properties may need to be adjusted to capture the full damage that is occurring.
Future work will include new seem designs, experimental testing and modeling done in LS-DYNA

15. SUBJECT TERMS
Adhesive Layer Effect, .30cal AP M2 Projectile, 762x39 PS Projectile, SPH, Aluminum 5083, SiC, DoP Expeminets, AutoDyn Sin

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PROGRESS REPORT
March 2014

Nicole A. Cicchetti, Bazle Z. (Gama) Haque,
Shridhar Yarlagadda, John W. Gillespie Jr.

MODELING AND SIMULATION OF CERAMIC ARRAYS TO IMPROVE BALLISTIC PERFORMANCE

TECHNICAL APPROACH

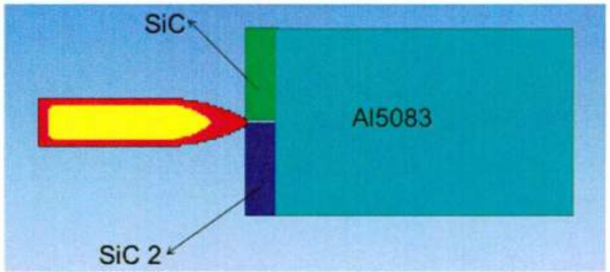
- The University of Delaware Center for Composite Materials (UD-CCM) is developing the next generation of lightweight hybrid ceramic/composite armor kits for Marine Corps tactical and combat vehicles
- The focus is on simulating and modeling the performance of ceramic/composite lightweight armor at seams and corners, and improving the armor's performance in these regions
- The ceramic/composite armor is comprised of composite backings, adhesives, ceramics and covers
- The tiles will be restricted to the sintered ceramics (SiC) due to the ability to fabricate SiC into complex geometries and cost analysis conducted in previous research
- Model ballistic experiments will validate the modeling done in simulation

TECHNICAL APPROACH

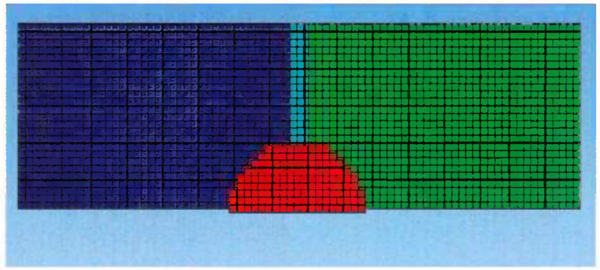
- Half-symmetric model is used in AutoDyn to simulate Depth of Penetration (DOP) experiments on SiC tile with and without a gap supported by solid Aluminum (Al5083)
- Impacts by .30cal AP-M2 projectile and are modeled using SPH elements in AutoDyn
- Center strike model validation runs with SiC tiles are conducted based on the DOP experiments described in reference - ARL-TR-2219, 2000
- Tile gap is found to increase the DOP as compared to baseline center impact
- Simulations were run on gap sizes 0.508 (20 mil) and 1.061 mm (40 mil) at the standard muzzle speed of 850 m/s
- DOP is the main measurement used to determine which geometry and configuration yield the best results.

TECHNICAL APPROACH, MODEL SET UP

Side View



Front View

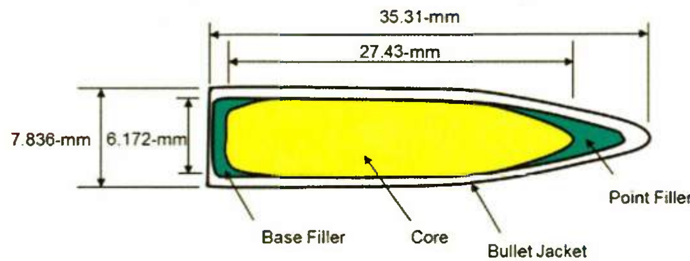


- ❑ Smoothed-particle hydrodynamics (SPH) used for all parts, SPH Size = 0.2
- ❑ SiC and SiC 2 are identical in properties and dimensions
  - ❑ Differentiated to show damage in each tile
- ❑ Clamp boundary condition used

Material Models

MATERIAL	EOS	STRENGTH MODEL	FAILURE MODEL
Steel Core	Polynomial	Johnson & Cook	Johnson & Cook
Lead Filler	Gruneisen	Piecewise Johnson & Cook	N/A
Copper Jacket	Linear	Piecewise Johnson & Cook	N/A
SiC Ceramic	Polynomial	JH-2	JH-2
Aluminum	Polynomial	Johnson & Cook	Johnson & Cook
S-Glass/Phenolic	Linear	LS-DYNA MAT162	LS-DYNA MAT162
Polymeric Foam	Linear	Non-linear Elastic	N/A
Adhesives & Interlayers	N/A	Cohesive Laws	Cohesive Laws

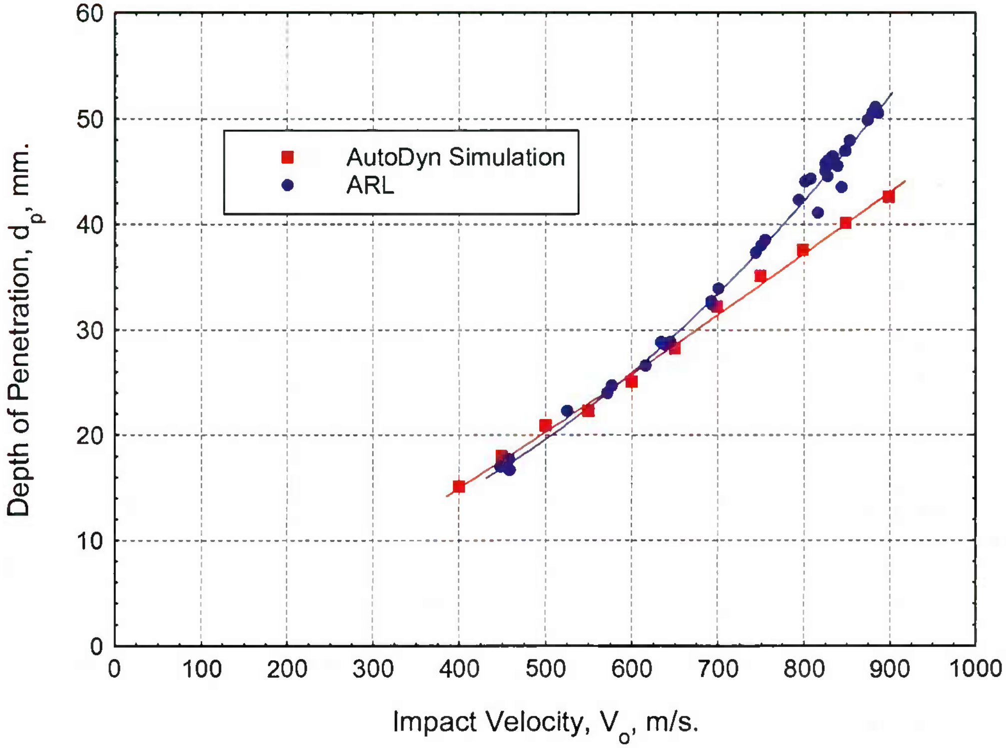
.30cal AP-M2 Projectile



Component	Material	Weight (g)
Jacket	Gilding Metal	4.2
Core	Hardened Steel - RC 63	5.3
Point Filler	Lead	0.8
Base Filler	Lead	0.5
Total Weight		**10.8**

MONOLITHIC Al5083 DOP AT SPH SIZE 0.2 COMPARED WITH ARL DATA

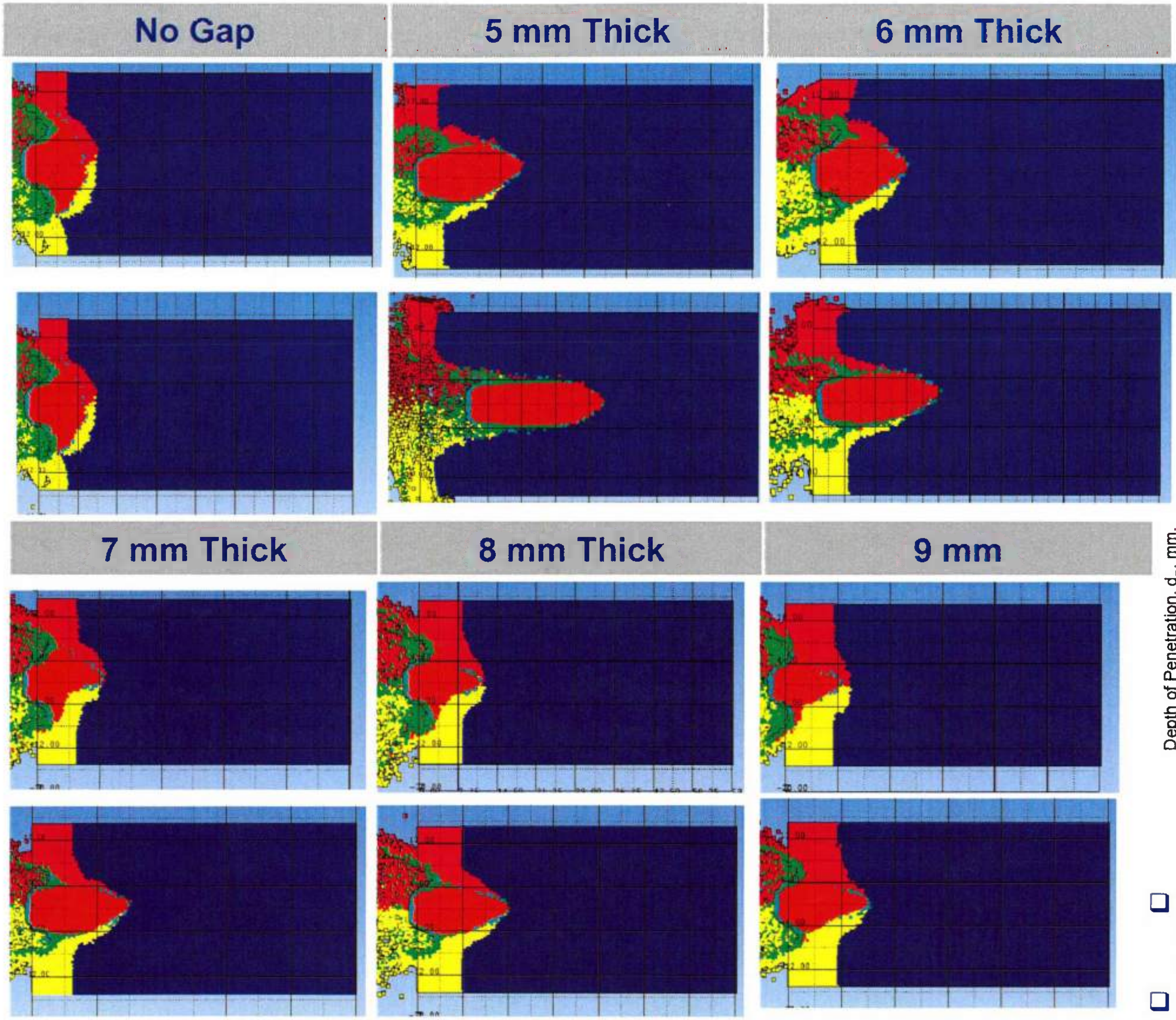
Monolithic Al5083 DOP	
Velocity (m/s)	DOP (mm)
400	15.0
450	17.9
500	20.8
550	22.2
600	25.0
650	28.1
700	32.1
750	35.0
800	37.5
850	40.0
900	42.5



- Simulation results do not show the same trend as the ARL experimental data
- Simulations will be extended over a larger range of Impact Velocities
- Material properties may be edited if the properties do not match the material properties used in the ARL experiments

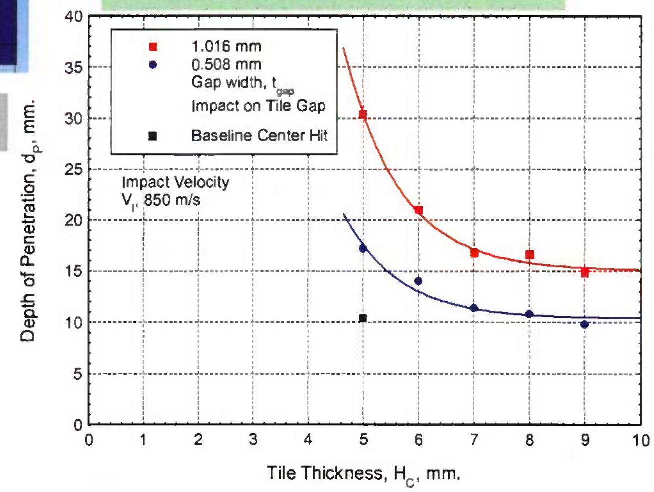
Moynihan, Thomas J., Shun-Chin Chou, and Audrey L. Mihalcin. *Application of the Depth-of-Penetration Test Methodology to Characterize Ceramics for Personnel Protection.* Rep. Aberdeen Proving Ground, MD: Army Research Laboratory, April 2000. Print.

EFFECT OF TILE THICKNESS ON DOP AT 850m/s GAP SIZE 0.508mm AND 1.016mm



Depth of Penetration on Baseline Tiles and Modified Tiles at 850 m/s

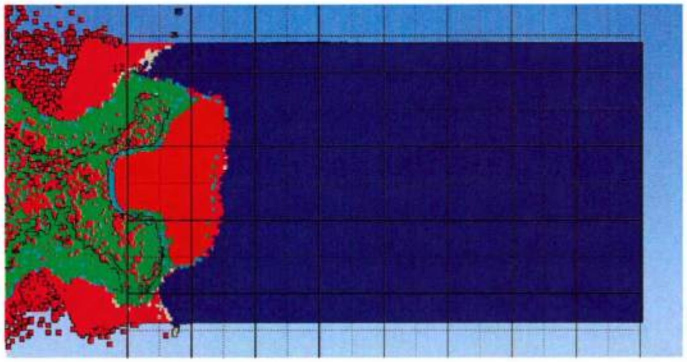
Tile Thickness H_c (mm)	Depth of Penetration, d_p, 0.508 mm Gap Size (mm)	Depth of Penetration, d_p, 1.061 mm Gap Size (mm)
5 (Baseline, No Gap)	10.3	10.3
5	17.2	30.3
6	14.0	21.0
7	11.4	16.8
8	10.8	16.6
9	9.8	14.8



- ❑ When the gap is held at 1.016 mm the baseline DOP of a center impacted tile cannot be effectively achieved
- ❑ A gap size of 0.508 mm allows the baseline to be achieved and gap size of 0.508 mm will be the gap size in use moving forward

ADHESIVE LAYER EFFECT

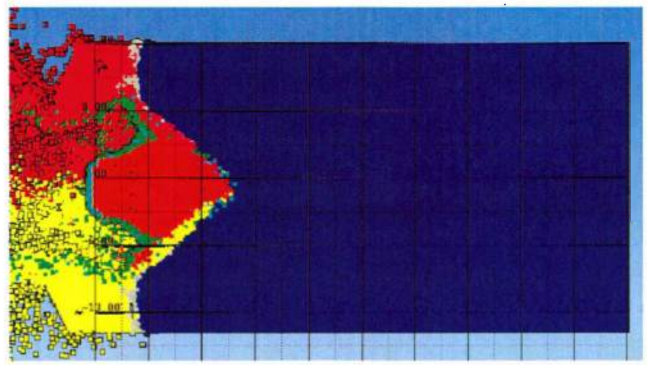
Center Impacted Single Tile



Adhesive Layer DOP Compared to No Adhesive Layer DOP, Gap 0.508 mm	
Adhesive Layer DOP (mm)	Baseline Center Impact with no Adhesive DOP (mm)
10.1	10.3

- An adhesive layer of Epoxy Resin was added in between the SiC tile and the Al backing
- The tile remained 5 mm thick

Impact on a Tile with 0.508 mm Gap

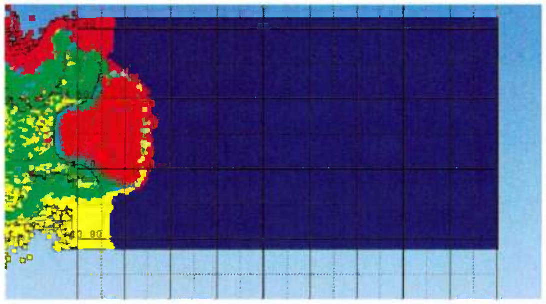


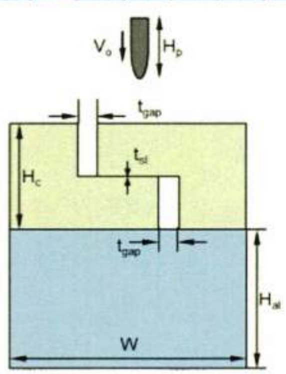
Adhesive Layer DOP Compared to 0.508 mm Gap with No Adhesive DOP	
Adhesive Layer DOP (mm)	Tile Gap 0.508 mm with No Adhesive DOP (mm)
13.9	17.2

- An adhesive layer of Epoxy Resin was added in between the SiC tile and the Al backing
- The tile remained 5 mm thick and the gap size at 0.508 mm to compare when no adhesive was added

STEP LADDER SEAM DESIGN

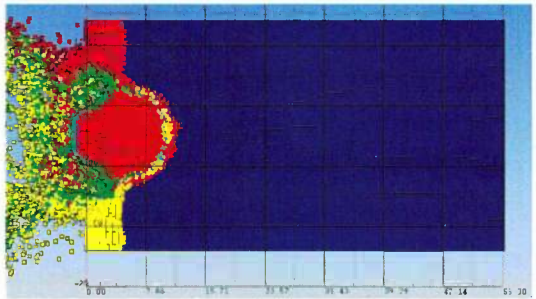
CENTER IMPACTED STEP LADDER
t_{sl}= 0

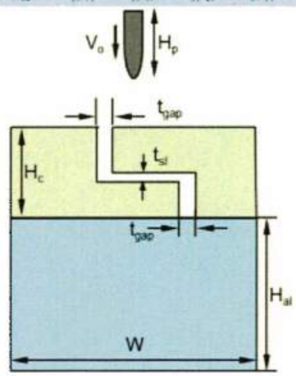




Part			
V_o	850 m/s	t_{sl}	0 mm
H_p	35.31 mm	H_{al}	50 mm
t_{gap}	0.508 mm	W	30 mm
H_c	5 mm		

CENTER IMPACTED STEP LADDER
t_{sl}= 0.2





Part			
V_o	850 m/s	t_{sl}	0.2 mm
H_p	35.31 mm	H_{al}	50 mm
t_{gap}	0.508 mm	W	30 mm
H_c	5 mm		

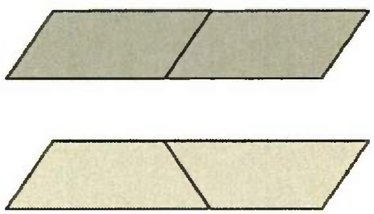
Step Ladder DOP

Step Ladder t_{sl} = 0 mm DOP (mm)	Step Ladder t_{sl} = 0.2 mm DOP (mm)	No Step Ladder DOP, Gap Size 0.508 mm (mm)	Baseline Center Impacted One Tile
9.2	11.8	17.2	10.3

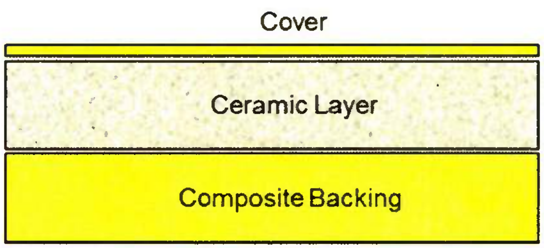
- An Step Ladders were created according to the schematics with presented specifications
- The tile remained 5 mm thick and the gap size at 0.508 mm to compare to the baseline results
- The DOP results are compare against center impacted single tile and standard 0.508 mm gap between two tiles

FUTURE WORK

- Angled Seams (a) and Cover plates (b) are proposed seam designs to be tested in the future
- Continued modeling and experimental tests will down select for the best solution and improvement to seam design
- Modeling will move from AutoDyn to LS-DYNA for increased computational power and the ability to model complex geometries



(a) Angled Seam



(b) Cover Plate

SUMMARY

- Simulations were run on:
  - Monolithic Al5083
    - Baseline
  - Proposed seam design of thickened edges
    - Inefficient solution
  - Ceramic tiles with and without gap with the adhesive layer modeled
    - AutoDyn accurately models the behavior of the adhesive
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